

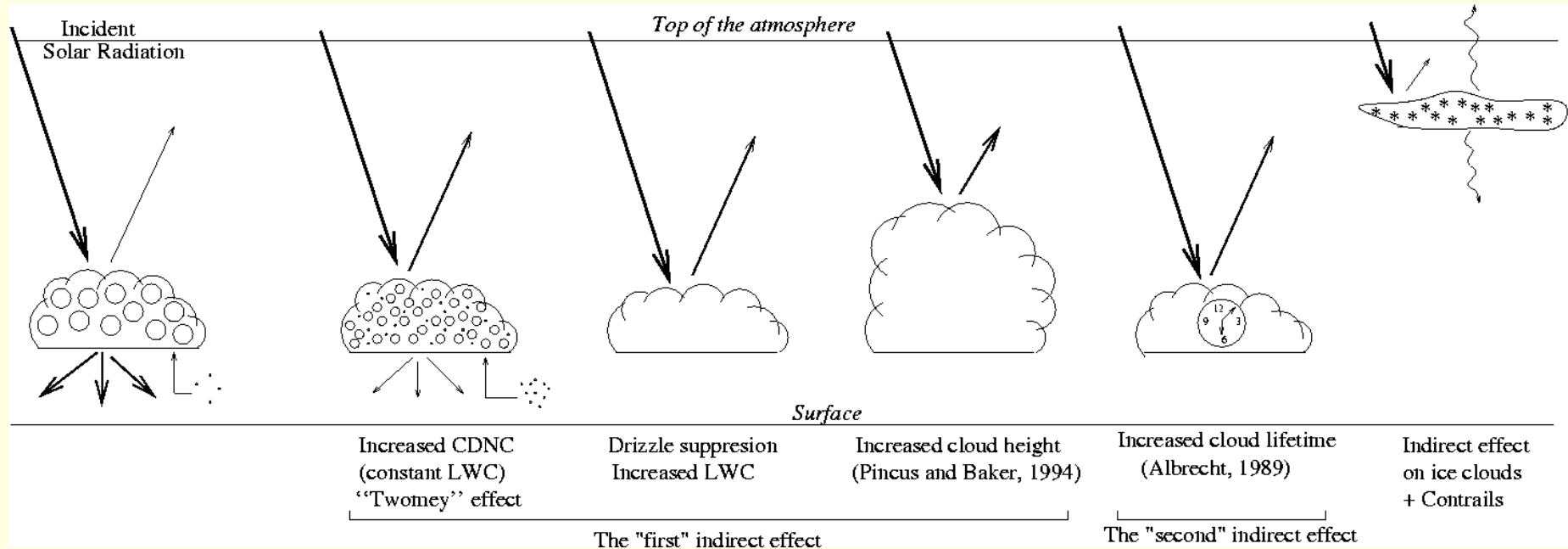
Direct and Strong Evidence of Aerosol Effects on Cloud & Precipitation from Long-term ARM Ground & A-Train Satellite Measurements

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University of Maryland

Indirect Effect

Haywood and Boucher *Revs. Geophys.* 2000



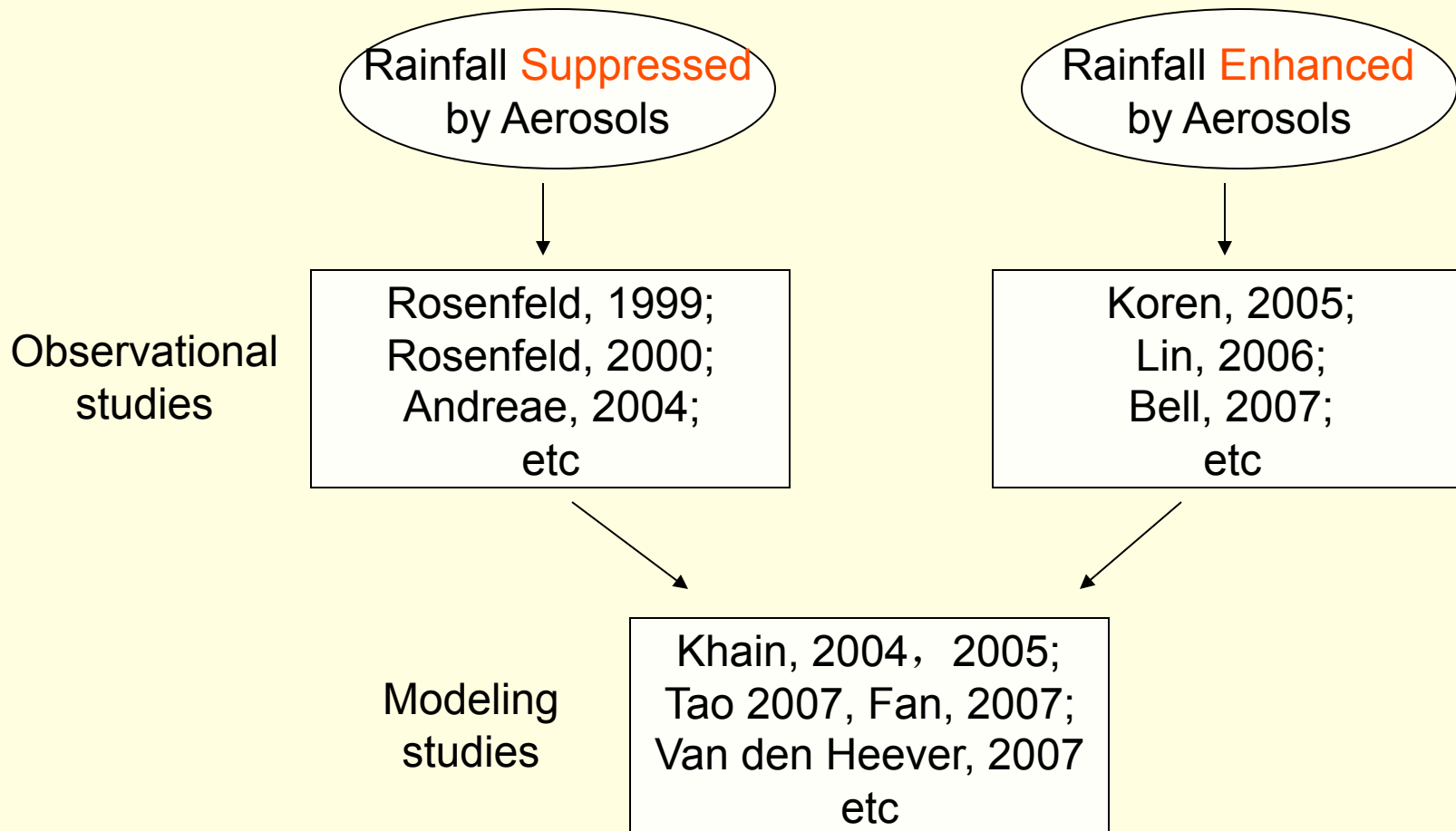
- 1) Increased CCN - reduces r_{eff}
- 2) Drizzle suppression - increases LWC
- 3) Increased cloud height
- 4) Increased cloud lifetime

'First' indirect effect

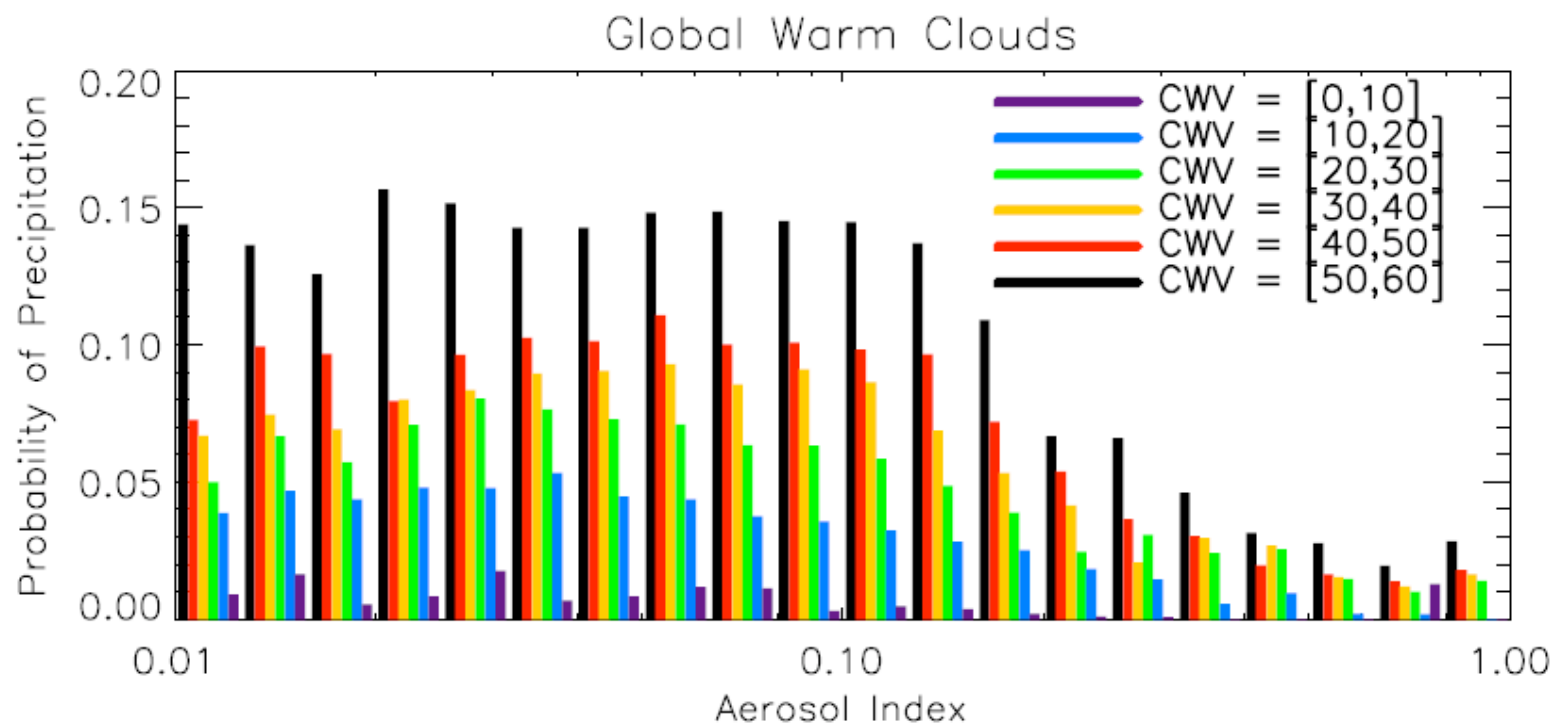
$$\tau \sim \frac{3LWP}{2r_{eff}}$$

'Second' indirect effect

A lot have been done concerning aerosol's impact on rainfall



Probability of Warm Cloud Precipitation



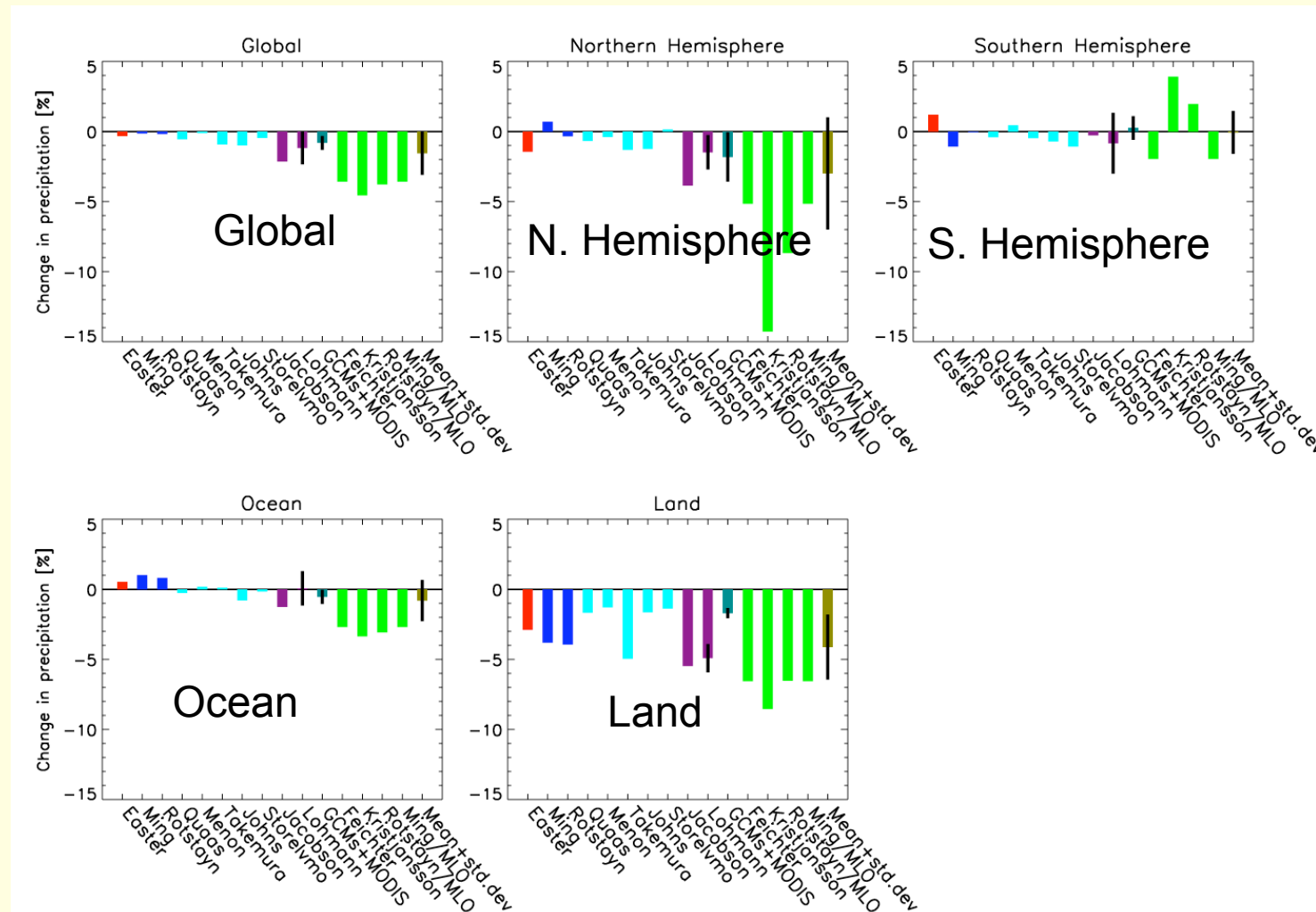
Global probability of warm cloud precipitation as a function of AI for Various column water vapor regimes. The units for CWV are kg/m²

[Lebstock, et al, 2008]

Global effects of pollution on precipitation

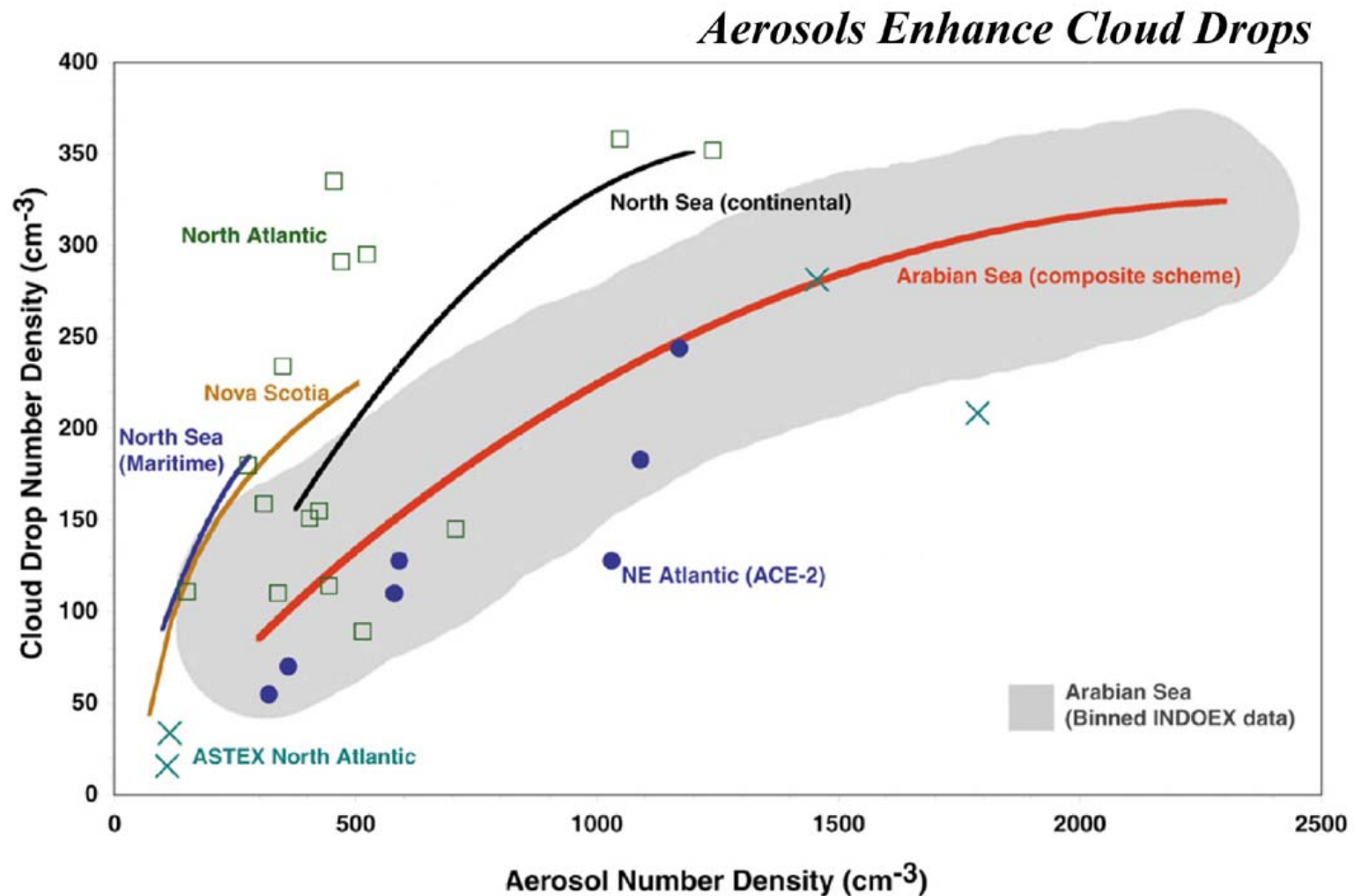
GCM-- estimates 0 to - 4.5% change in global mean precipitation over the last 100 years due to the direct and indirect aerosol effects.

The differences among models over land range from -1.5% to -8.5%.

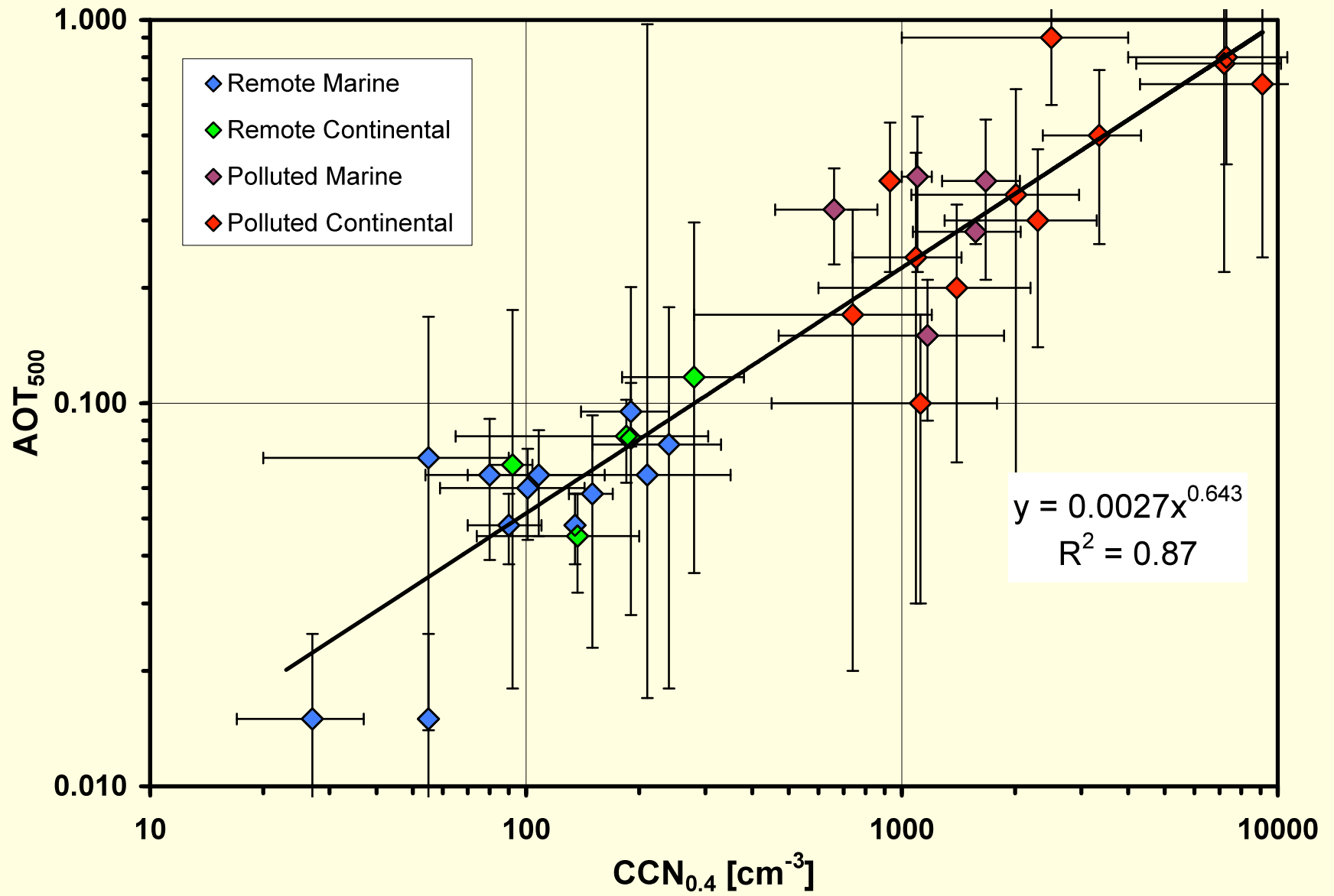


Aerosol Microphysical Effect
(Twomey Effect &
Apparent Anti-Twomey Effect)

Fig. 2. In-situ Measurements of Aerosols and Clouds

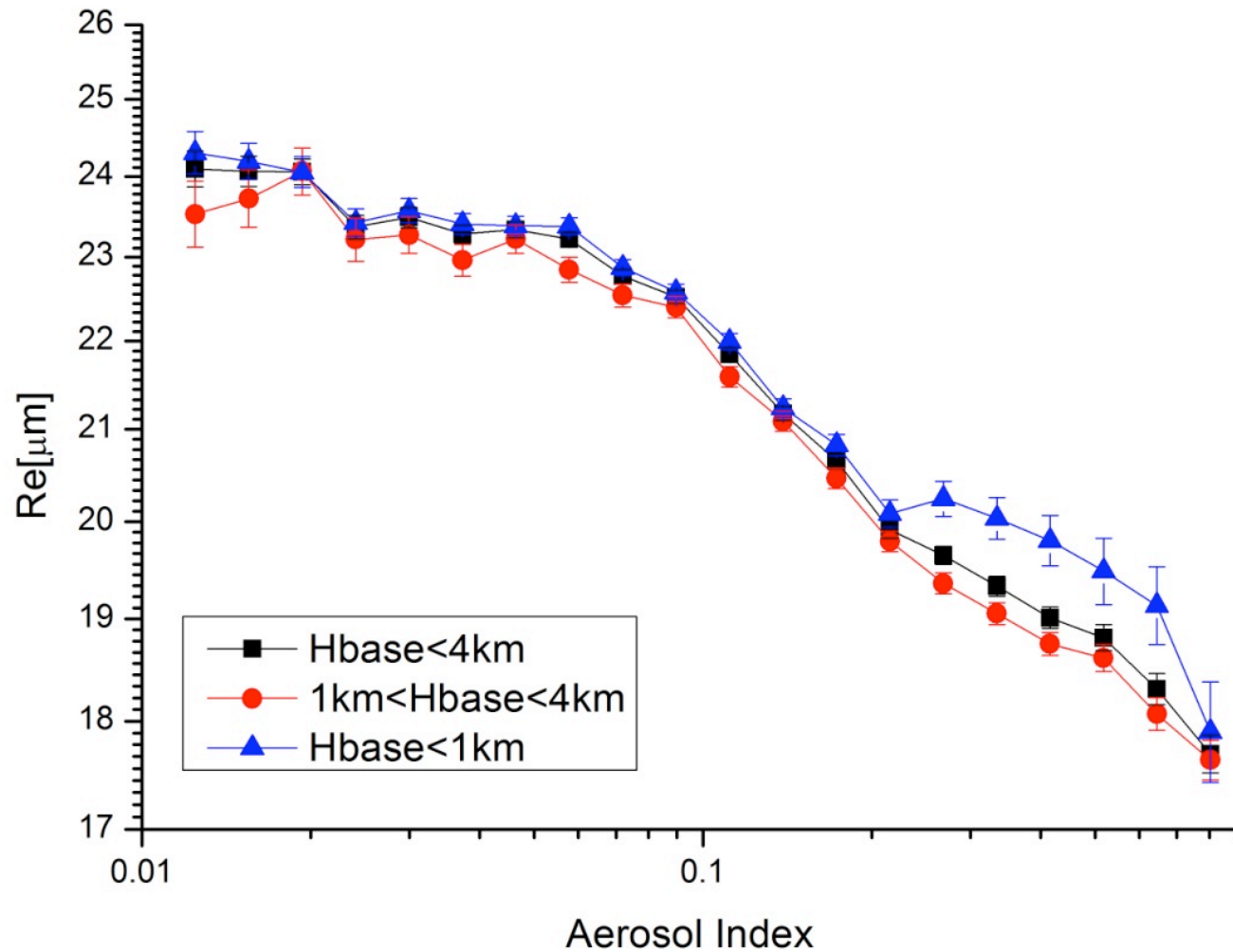


Ref: Ramanathan, Crutzen, Kiehl and Rosenfeld, *Science* 2001.

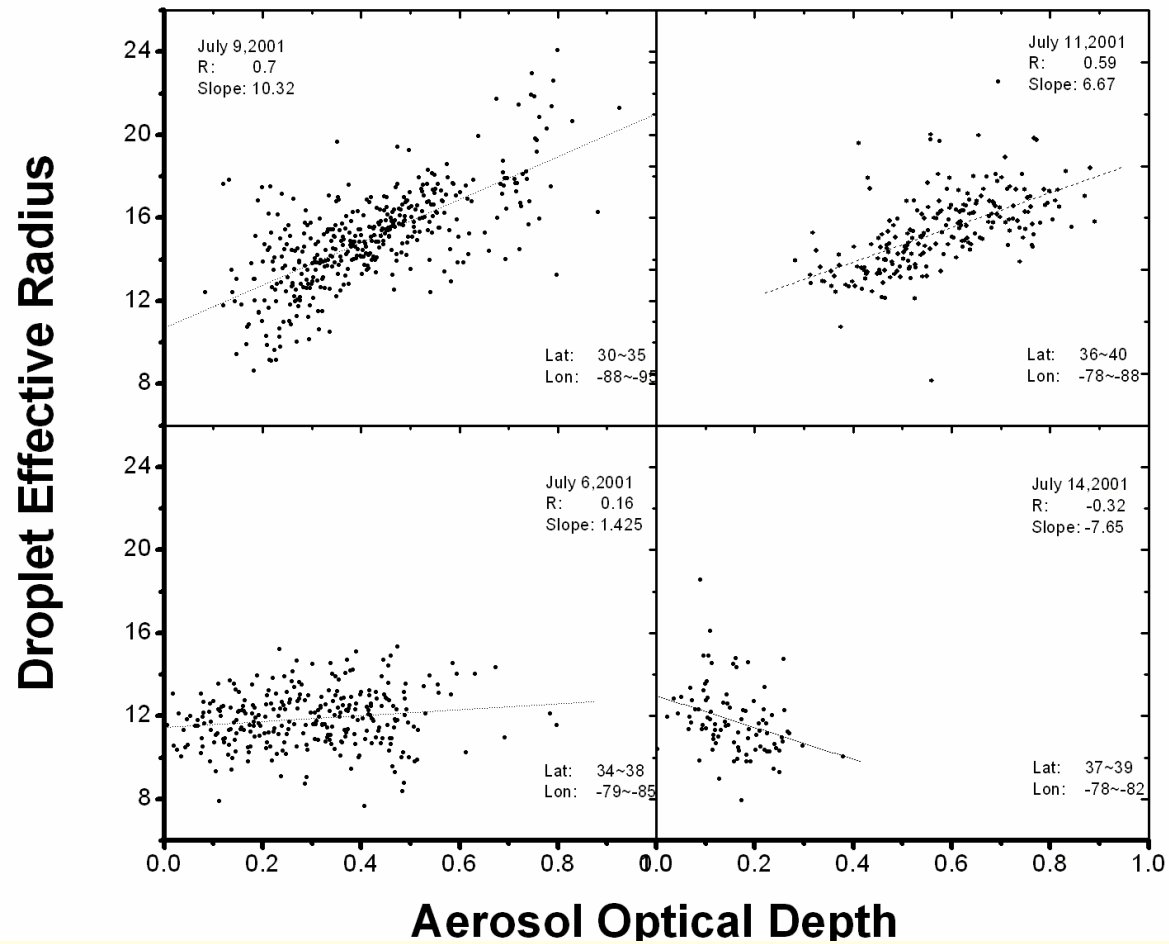


Andreae, ACPD 2008

Aerosol Impact on Cloud Particle Size

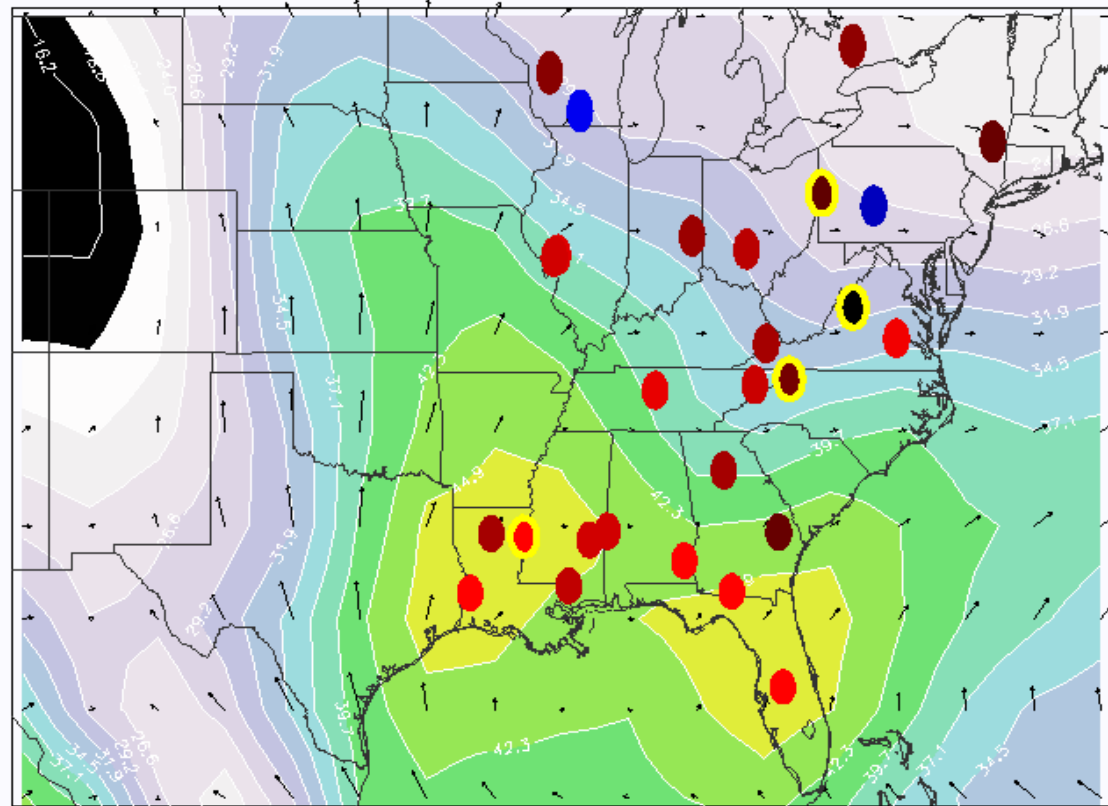


DER-AOD relationship



Yuan et al. (2008, JGR)

AIE efficiency distribution



Yuan et al. (2008)

Global Analysis

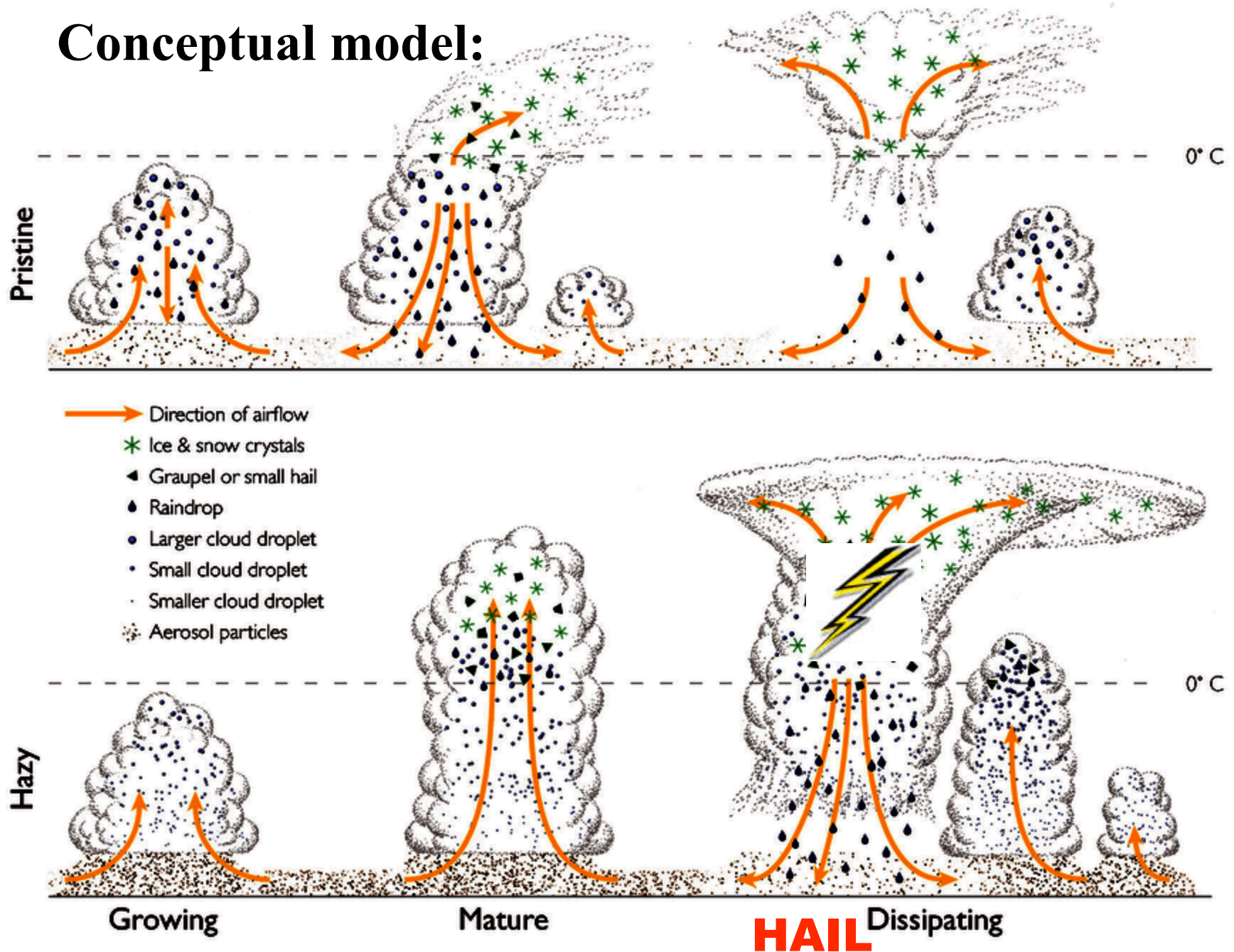
Region	Latitude range	Longitude range	Dominant Aerosol/Cloud Types	Period	AIE efficiency	Sample size
North Atlantic	10-20N	20-40 W	Dust, Stratocumulus	June-August, 2002	Negative	99,978
South Atlantic	5-20S	5E-20W	Smoke, Stratocumulus	June-August,2002	Negative	100,377
Southern Pacific	5-25S	75-105W	Sea salt, sulfate and pollution, Stratocumulus	August-October, 2002	Negative	74,216
Indian Ocean	12-20N	60-70E	Dust with pollution, Trade cumulus	June-August, 2002	Negative	94,023
India	13-24N	70-85E	Mixture of sulfate, dust, sea salt and smoke, cumulus	June-August,2002	Neutral	53,888
Amazonia	8S-12N	44-76W	Mainly smoke	August-October, 2002	Negative	672,421
Southeastern China	23-43N	100-120E	Mixture, cumulus	June-August,2002	Positive	179,533

Student-t test indicates except India the difference among different loading of aerosols are statistically significant at least at the 95% level

Yuan et al (2008)

Aerosol Thermodynamic Effect
(Invigoration effect, but not
just for ice clouds)

Conceptual model:



Rosenfeld et al. (2008)

Graphics by Robert Simmon, NASA

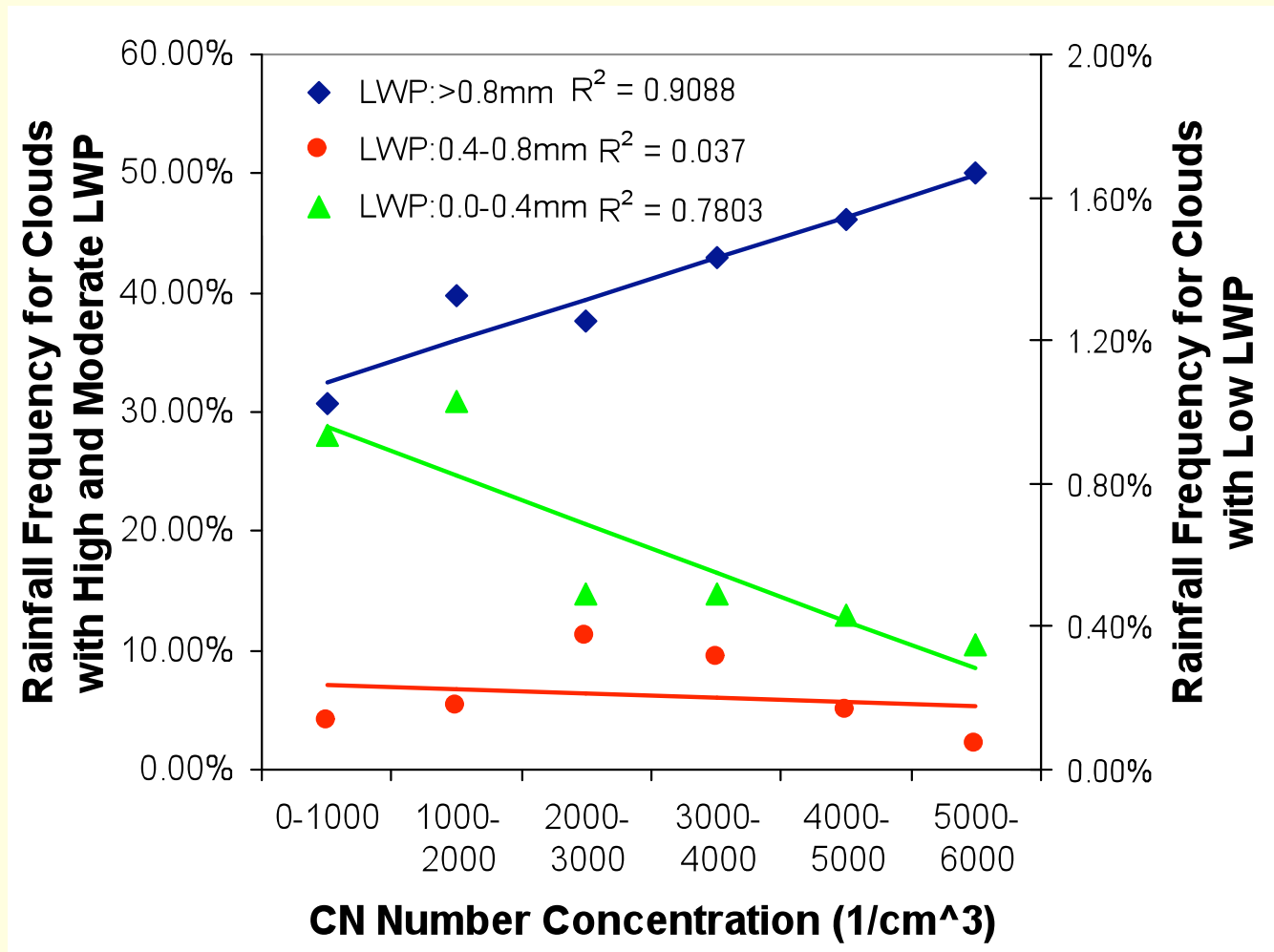
A lot have been done on the effect of aerosol on rainfall amount or intensity, but little has been done for rain frequency!

While rain amount and frequency change in harmony in general, the impact of aerosol on initiation of rain is likely to be more significant than rain amount, as the latter is dictated more by dynamics and abundance of available water

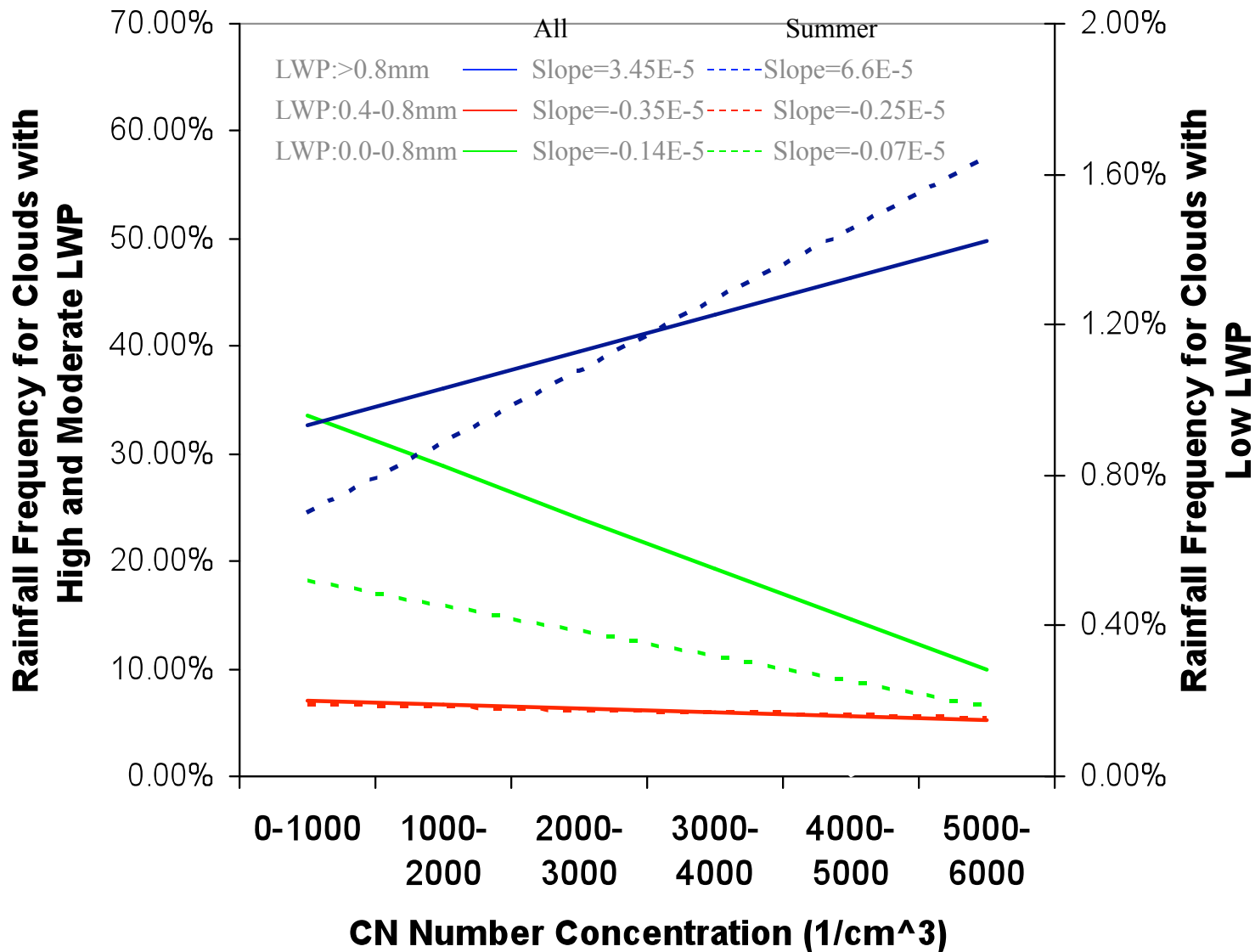
Datasets Used

- Daily ARM SGP data 2003-2008 (~20000 data samples)
- Most complete and highest quality measurements of aerosol, cloud, atmospheric state
- Key variables used:
 - Aerosol CN number concentration on the ground
 - Tipping bucket rain gauge
 - LWP from microwave radiometer
 - Cloud bottom and top heights from cloud radar & lidar
 - NOAA/NCAR Reanalysis
 - MODIS cloud particle size

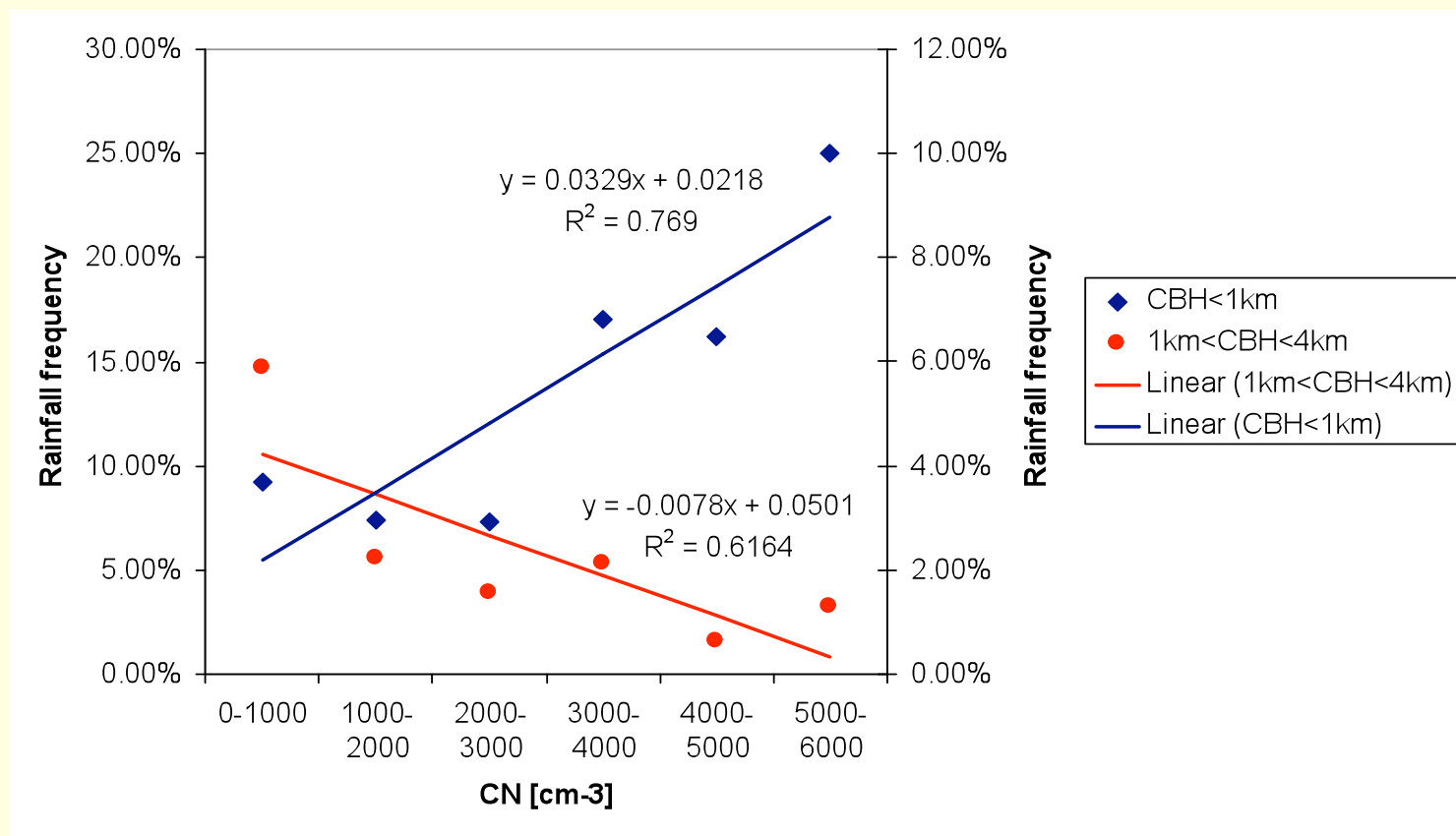
Rainfall Frequency for clouds with different liquid water path at SGP (All-Season Data)

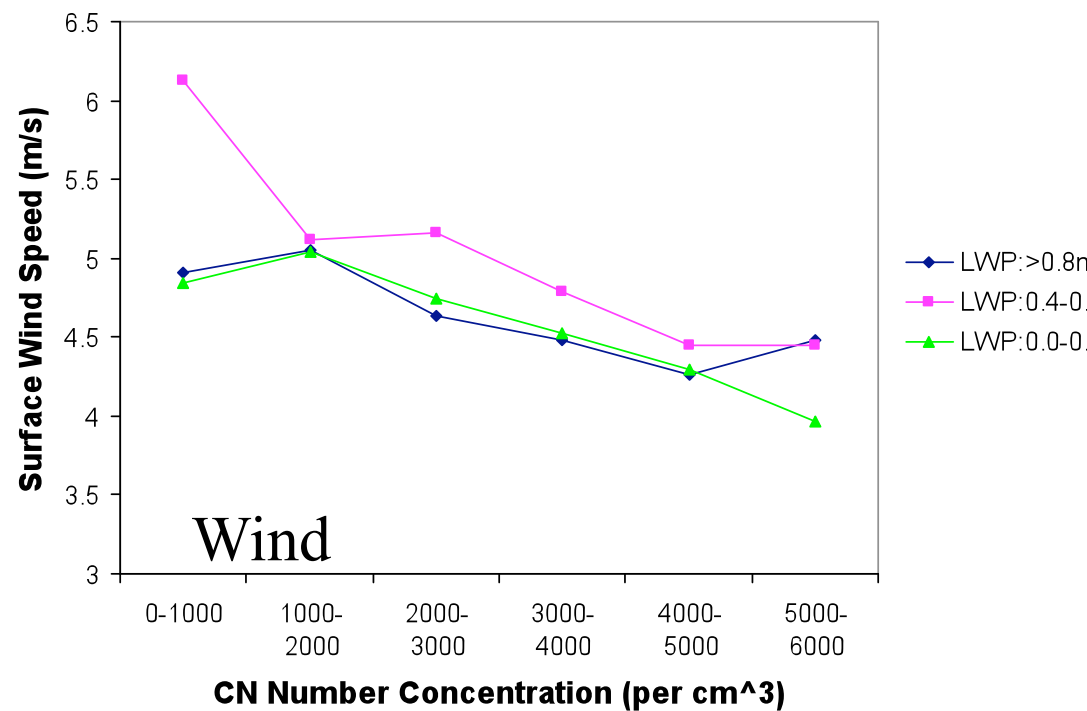
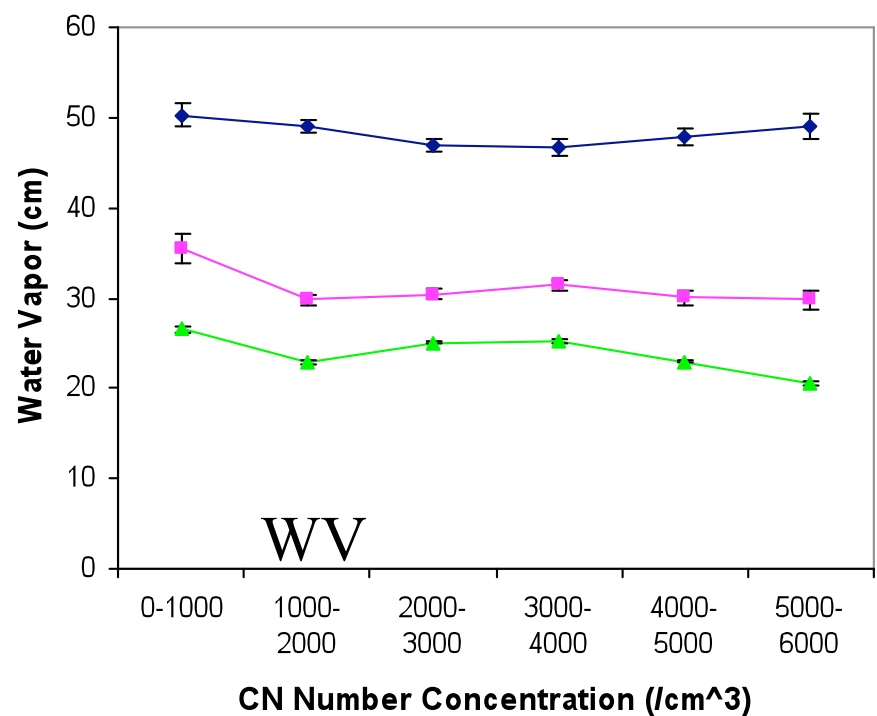
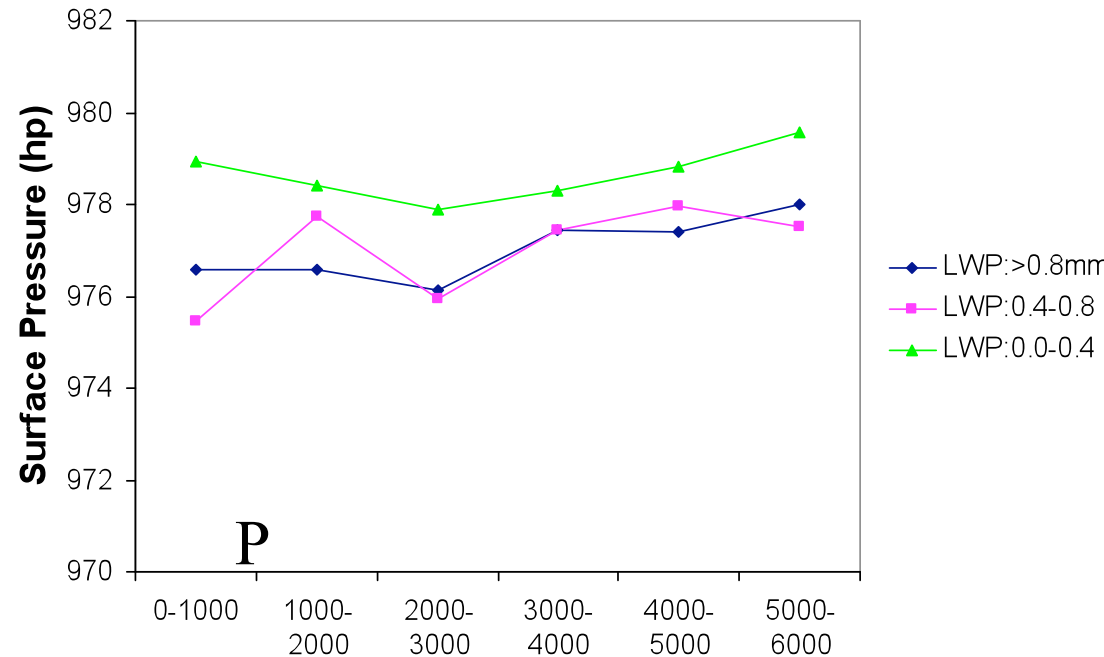
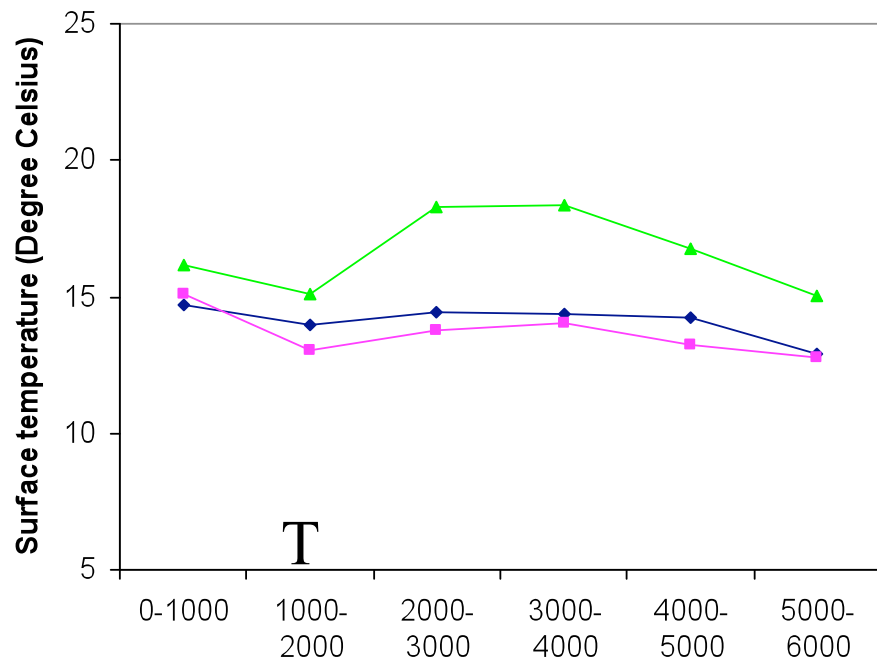


Comparison of the Results Obtained in All Seasons and in Summer Only

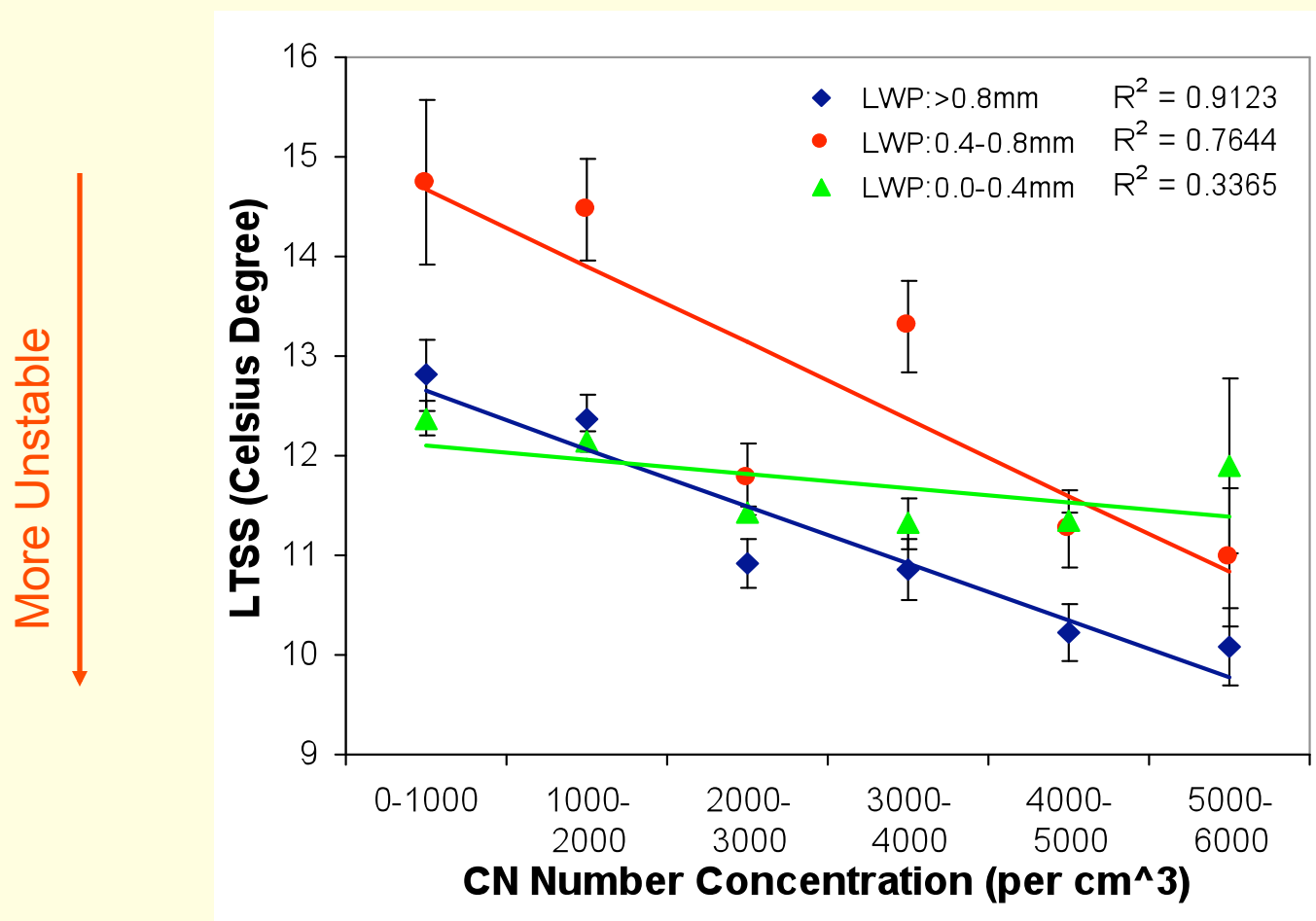


Summer



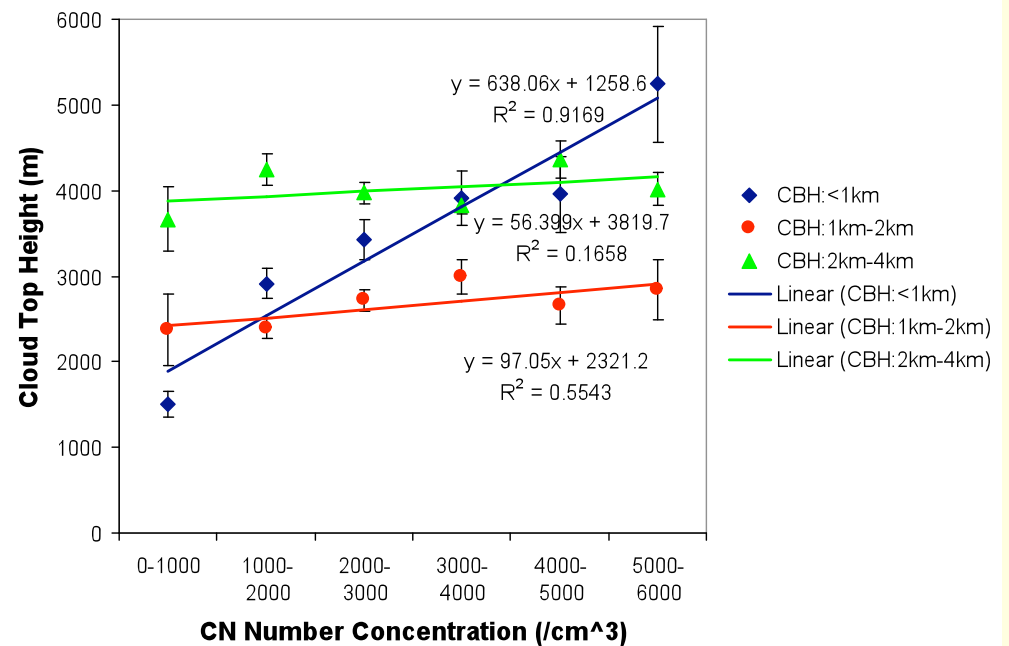
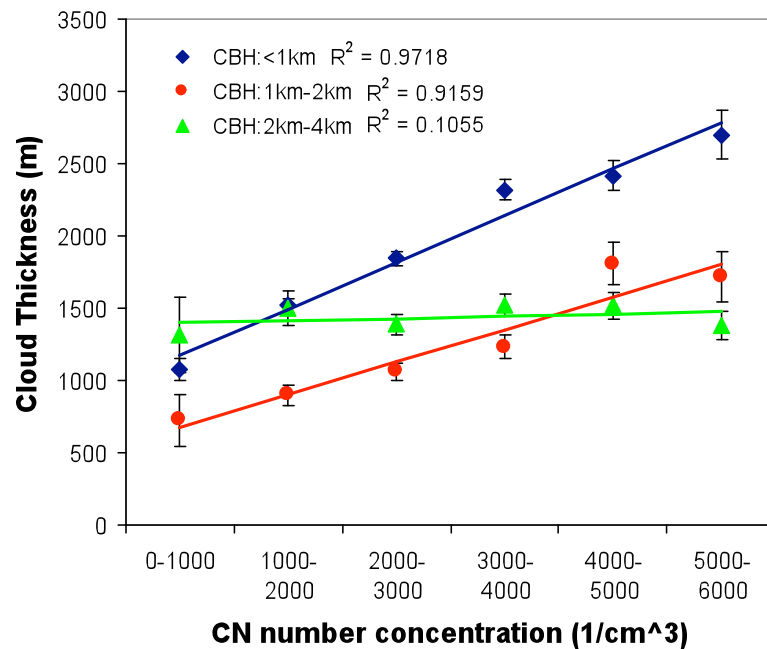


Lower Tropospheric Static Stability (LTSS)

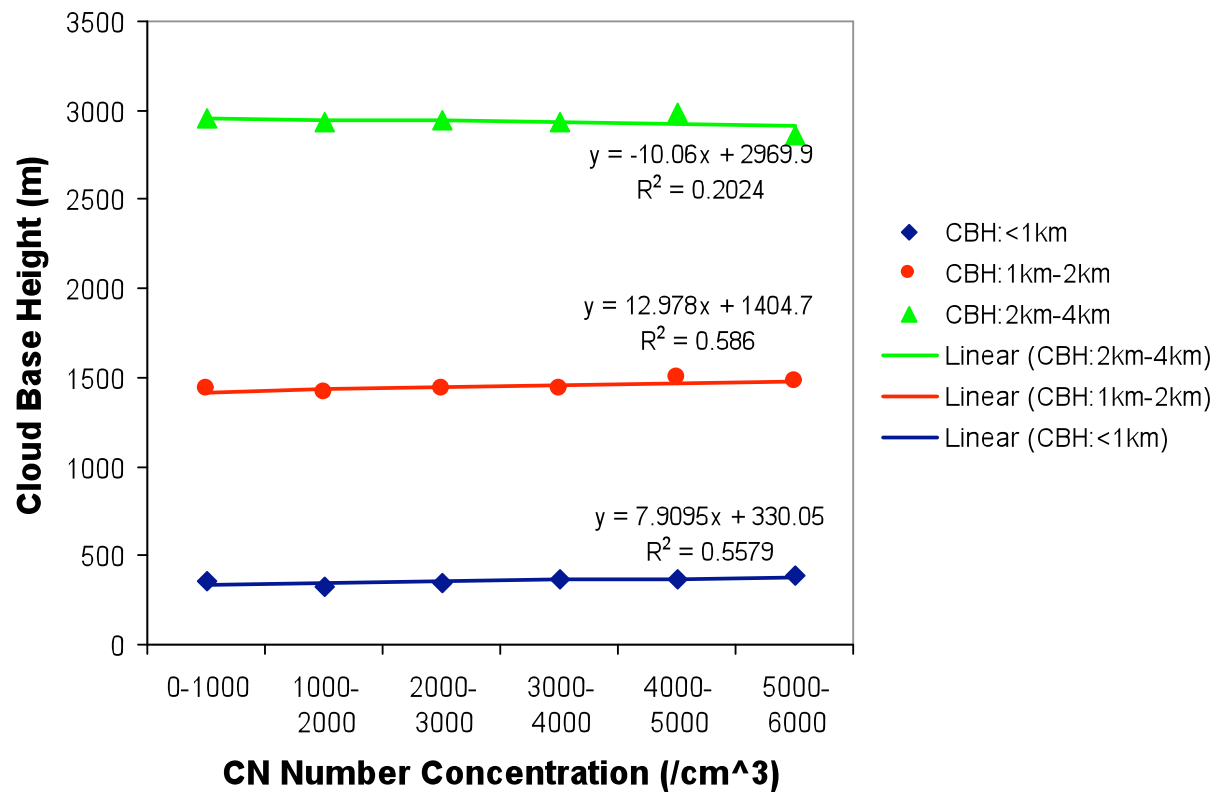


LTSS is defined as the difference of potential temperature between 700hPa and the surface [Klein and Hartmann, 1993].

Cloud Thickness and Top Height for clouds with different cloud base heights

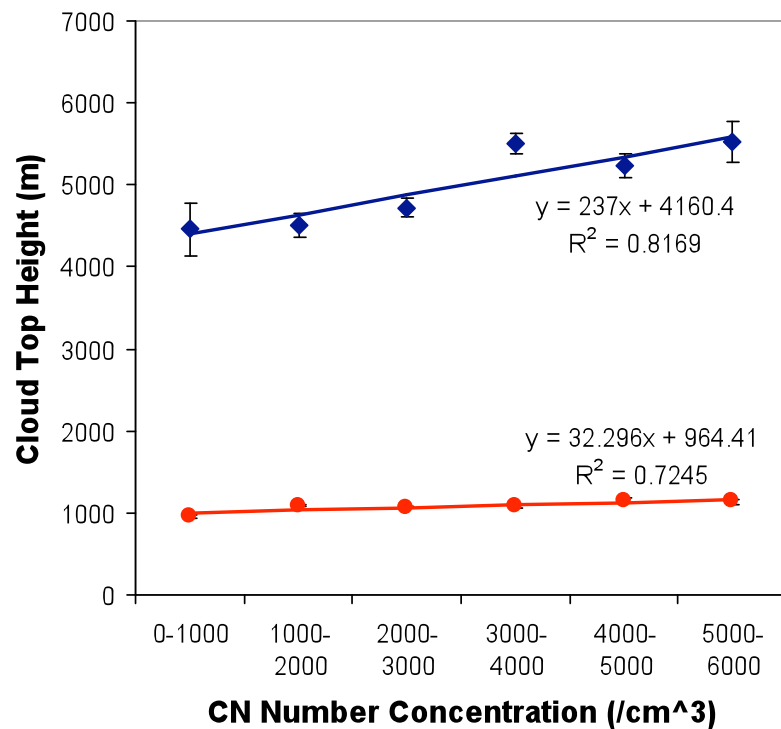


Cloud Base Heights

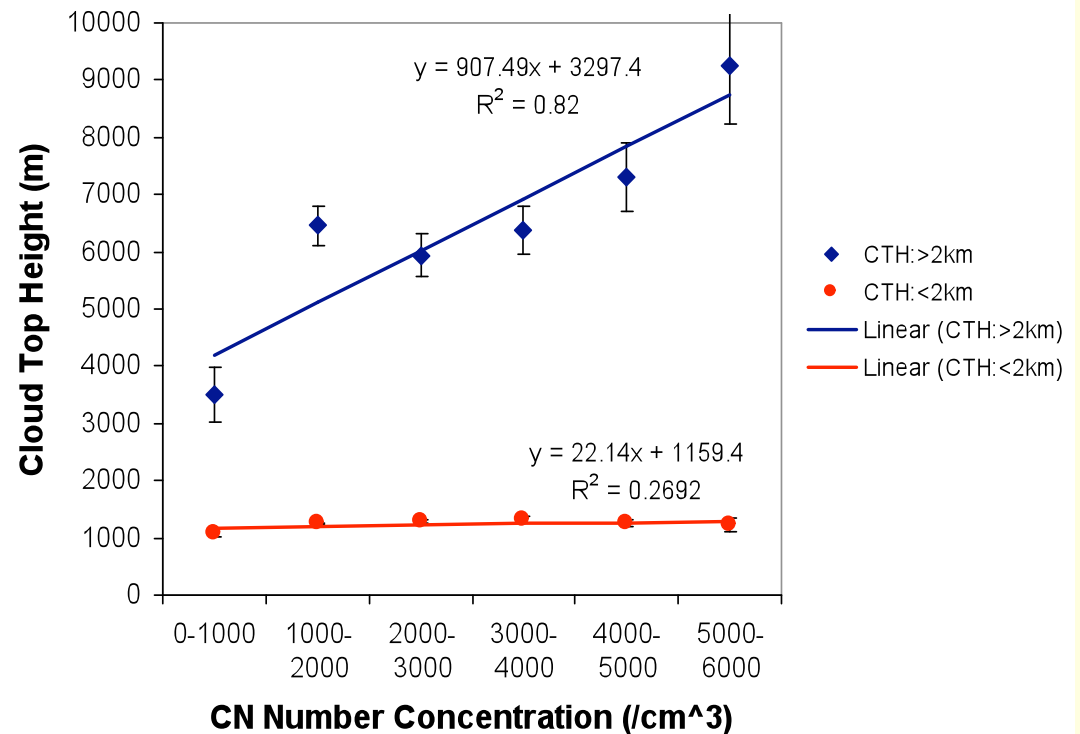


Cloud Top Heights (for clouds of cloud base <1km)

All Seasons



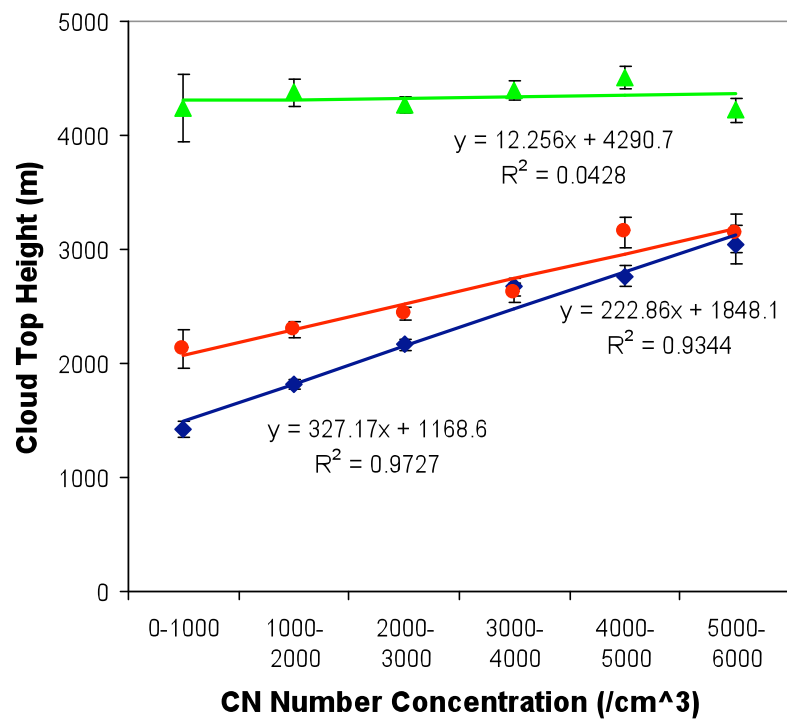
Summer Only



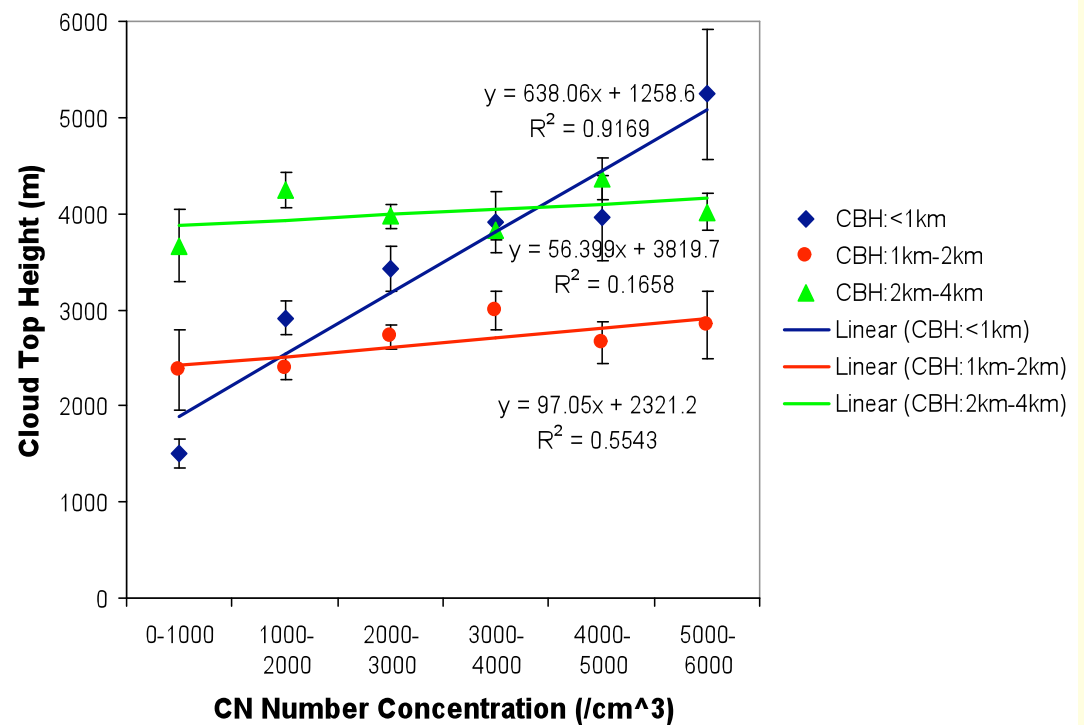
For clouds with CBH<1km, clouds are classified into two categories with cloud top heights greater (blue) and less than (red) 2km.

Cloud Top Heights

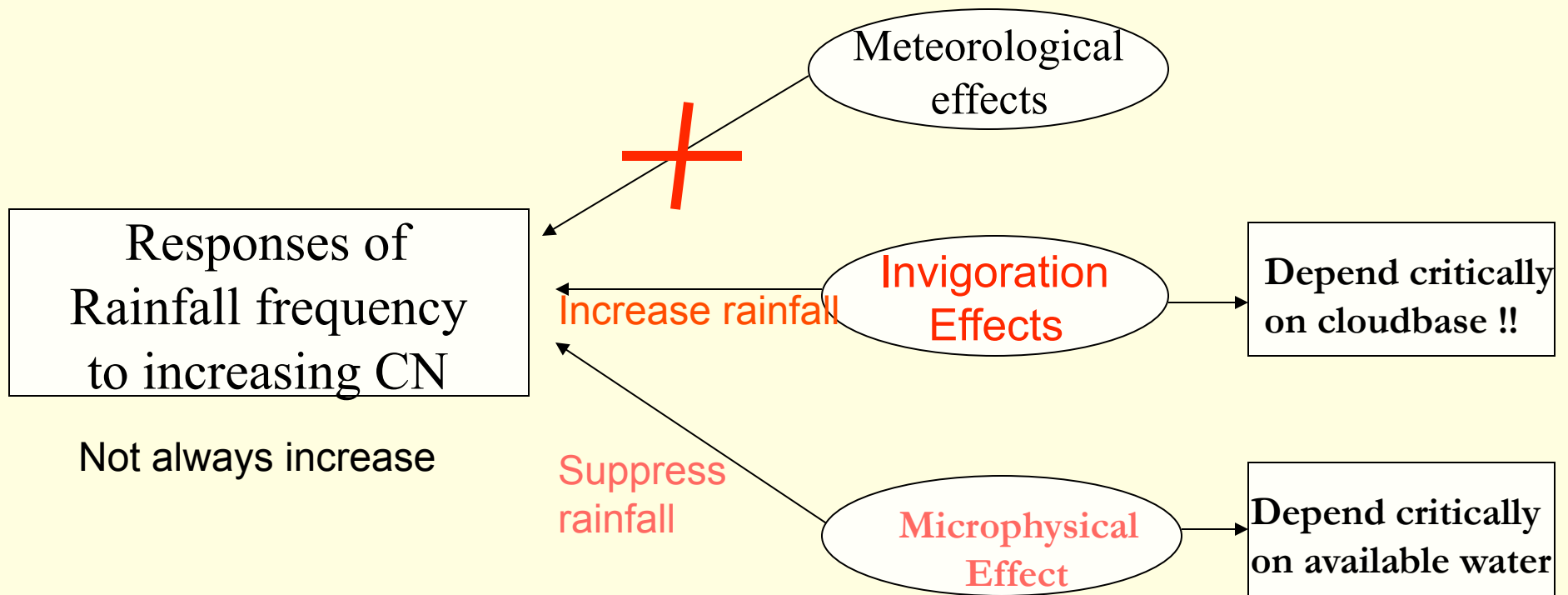
All Seasons



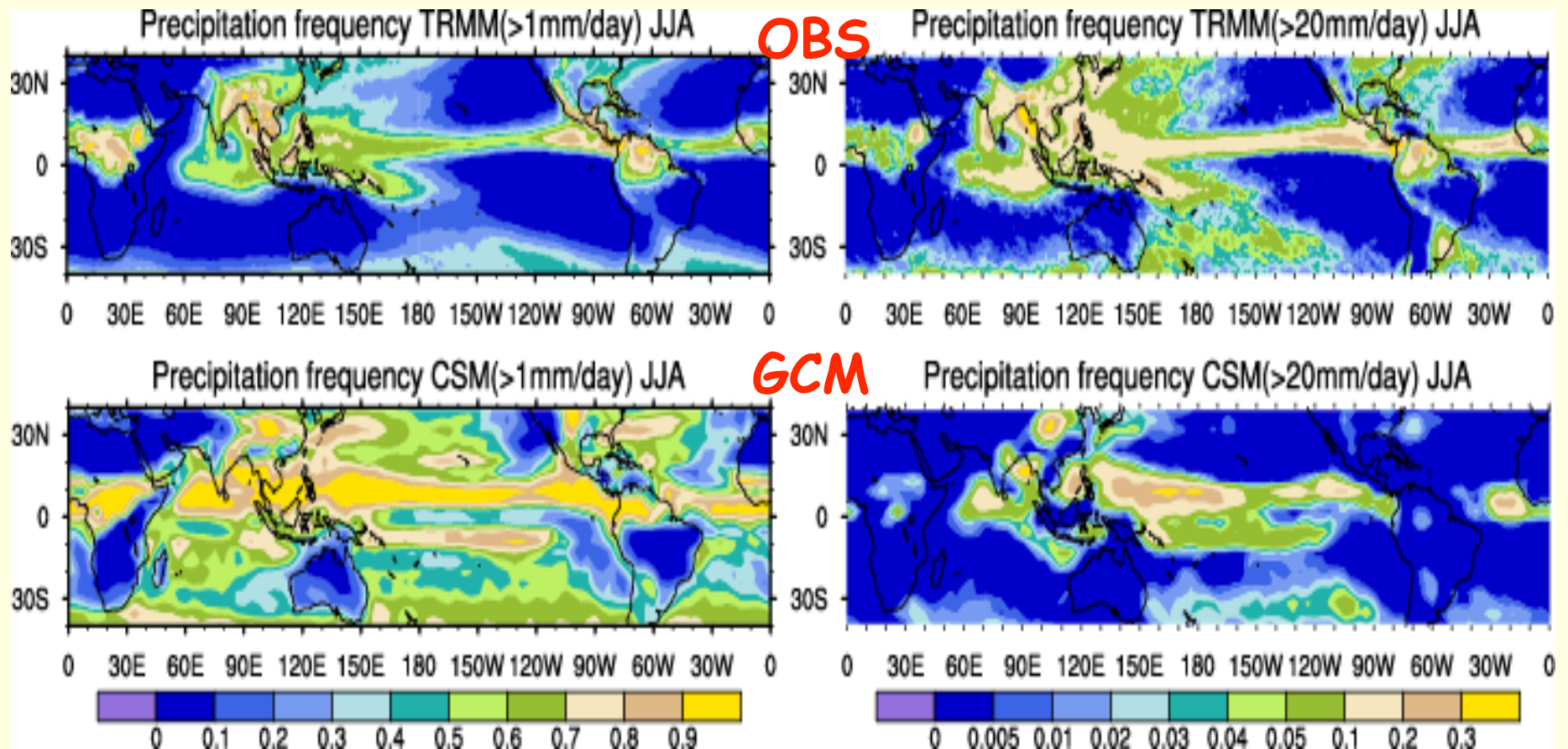
Summer Only



Competition of two opposite effects



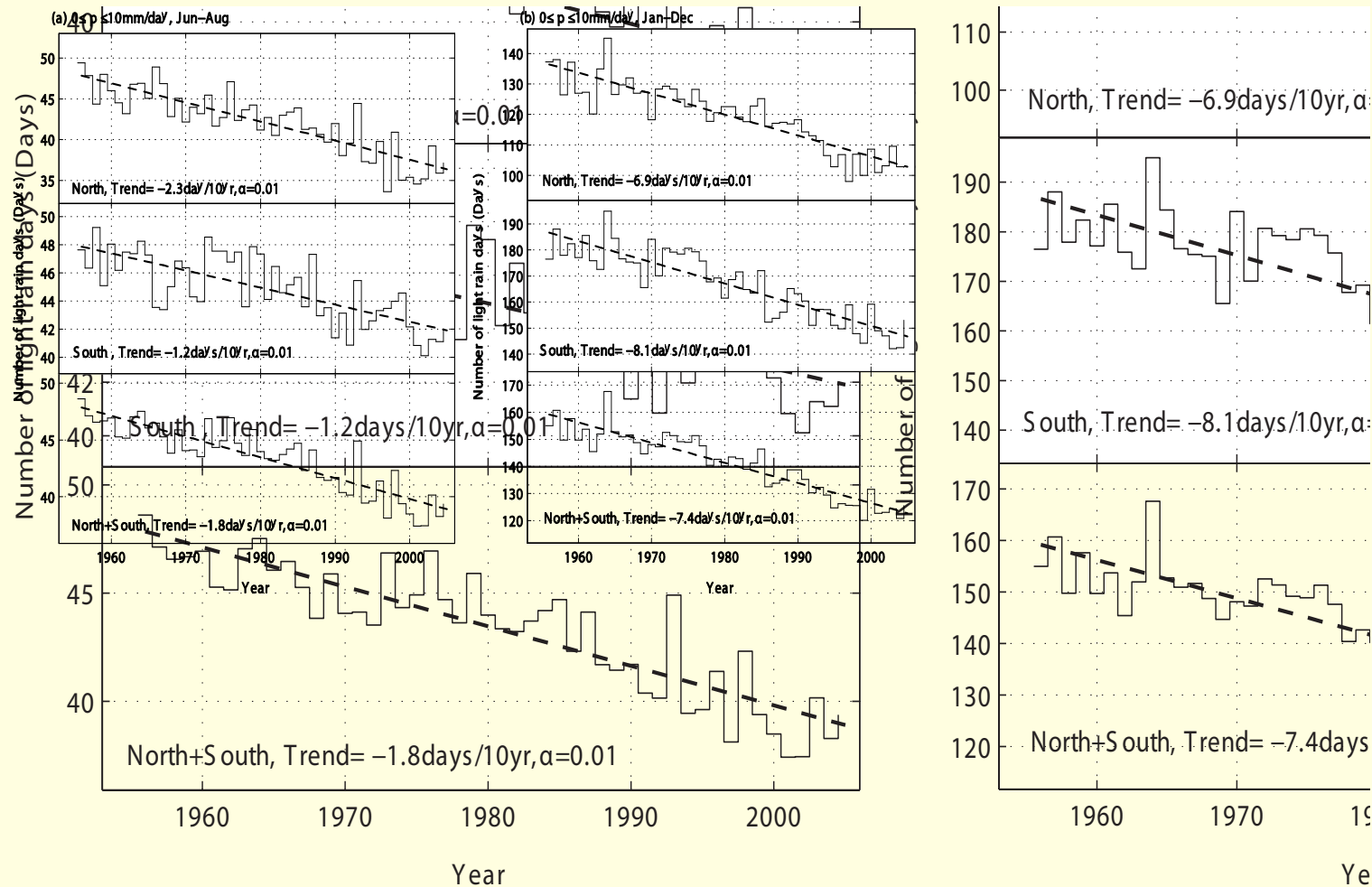
Precipitation Frequency



JJA (June, July and August) daily precipitation frequency (%)
(>1 mm day⁻¹, left; >20 mm day⁻¹, right)

Wu et al. (2007, GRL)

Time series of number of days for light rain (<10mm/day) from 1956-2005 (left: JJA; right: Jan-Dec)



Qian et al. (2009)

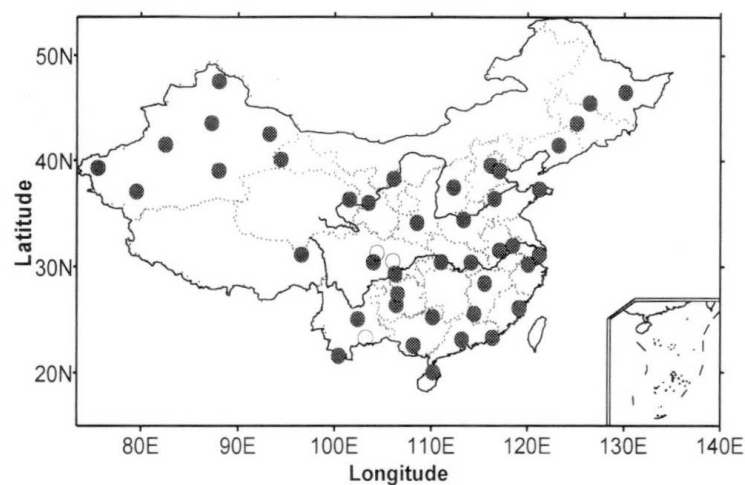


Figure 1. Locations of 46 solar radiation stations in China.

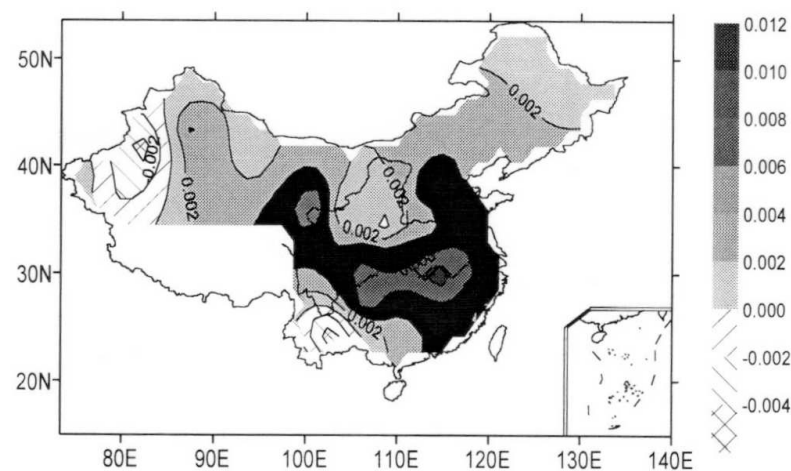


Figure 13. The linear trend (yr^{-1}) of AOD over China mainland.

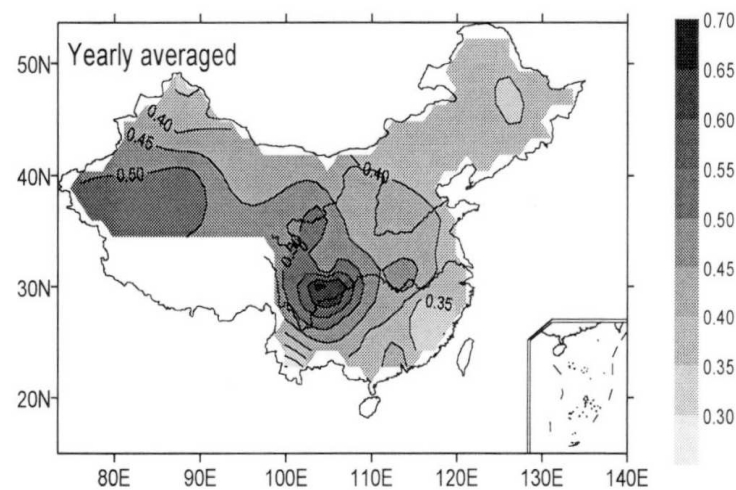


Figure 2. Distribution of multiyear mean (1961-1990) AOD over China.

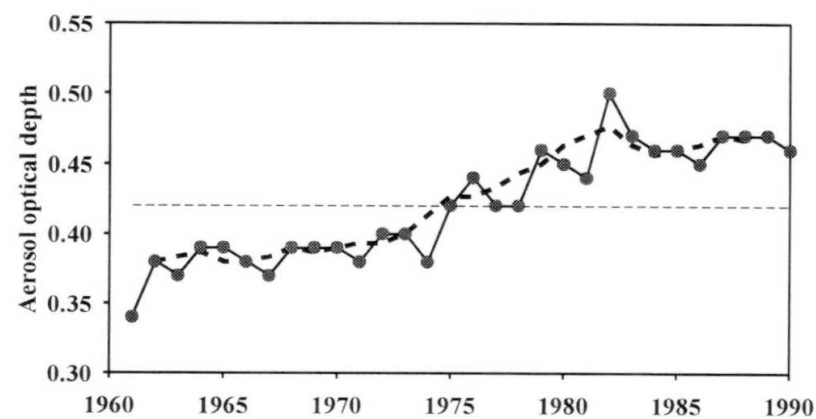


Figure 14. Yearly mean AOD variation curve of 44 stations averaged from 1961 to 1990.
(The broken line shows the three-years running average.)

ARM Mobile Facility Deployment in Shouxian



NEWS FEATURE

24 SEPTEMBER 2010

Cloudy with a chance of science

When American and Chinese scientists agreed to measure pollution and dust over China, nobody foresaw how difficult it would be. **Jane Qiu** reports.

It is meteorological heresy in the dusty towns of Shandong in eastern China was burning with indignation. It was May 2008, and the exasperated courtier was fumed with sophisticated climate-sensing instruments that had just arrived on loan from the United States Department of Energy (DoE). The bureau had been expecting the equipment earlier, but it had been held up by US Chinese customs officials for more than two months.

A group of climate researchers and government officials from China and the United States eagerly inspected the new arrivals, which included a cloud radar, a lidar-made lidar (a radar-like instrument that sends out laser beams rather than microwaves) and sensors for studying various features in the atmosphere and the radiation from the sun. "We can do great things with these here," said Zhaojun Li, an atmospheric scientist at the University of Maryland at College Park, who was leading the Bin-Air-American collaborative effort.

Over the next few months, these instruments would be pointed up into the Chinese sky to monitor and study aerosols — tiny airborne particles such as dust and soot. The researchers were particularly interested in tracing how aerosols alter the transparency of clouds by influencing whether those droplets grow, how high they cloud, how much sunlight they reflect and

how long they persist. At present, atmospheric researchers have only a rudimentary understanding of how aerosols affect clouds and that ignorance is one of the major sources of uncertainty in forecasts of future climate.

For aerosol experts, China's sky is close to heaven. The country has high concentrations of particles arising from pollution as well as natural dust blowing in from surrounding deserts. Researchers expected that data from such a particle-rich atmosphere would help to resolve major questions about aerosols and climate. At the same time, it was hoped that the project, staged at four sites across China (see map), would reap political rewards. The joint collaborative, conducted under the umbrella of the DoE's Atmospheric Radiation

Measurements (ARM) programme, was viewed as a sign of China's movement towards openness. "This kind of collaboration would have been inconceivable ten years ago," says Thomas Ackerman, an atmospheric scientist at the University of Washington in Seattle.

The political winds had not, however, blown from favourably. With much restriction, the DoE had to alter its usual mode of operation and search for lower-quality data and a smaller range of measurements than expected. "Between the heights of hope and the depths of despair, it was the most up-and-down deployment we have ever had," says Warren Weber, ARM's chief scientist and an atmospheric scientist at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

The stakes are high because the data collected by the ARM programme will be used to improve the way that climate models simulate clouds and aerosols. When the programme was created in 1986, it collected measurements only at fixed sites within the United States. "But it soon dawned on us that we could reach saturation as possible from a few climate systems around the world to build up a complete picture of global climate change," says Weber.

This resulted in a mobile facility, built in 2004, that contains most of the remote-sensing instruments present at the fixed sites. Each year,

CLIMATE SCIENCE

464

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Jana Qiu writes for *Nature* from Beijing.

Summary

- Aerosols appear to have very significant impact on cloud and precipitation even on *long-term mean, not just for individual cases*.
- The net impact on precipitation appear to depend on the *relative strength of aerosol microphysical effect (ME) and thermodynamic effect (TE)*.
- ME is dictated by cloud liquid water path, while TE depends critically on cloud base height.
- Cloud top height and thickness are apparently related to aerosol concentration in the PBL for low-base clouds, but no effect on high-base clouds.
- The aerosol effects are much stronger in summer than in other seasons, presumably due to its high frequency of convective clouds.